A COMPARISON OF THE REFLECTANCE CHARACTERISTICS OF VARIOUS SHADES OF THE COLORS RED AND GREEN

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by

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CHAPTER I

THE PROBLEM AND ITS HISTORY

In 1959 Harold C. Kulla presented a thesis to Drake University in which it was shown that many students and textbooks have an incorrect idea of why an object displays the color it does. This incorrect traditional view of color states that an object reflects wavelengths of its own color and absorbs all other colors. Kulla, in analyzing various shades of blue showed that blue surfaces reflect predominatly blue wavelengths of light but also reflect the wavelengths of the other colors to some degree. Kulla proceeded to plot his data; per cent of light reflected against wavelengths.[1]

Upon studying the curves of Kulla's data it was noticed that in all samples the blue wavelengths showed a maximum reflectance as might be expected, but also in each instance the complementary color yellow showed a minimum reflectance.

The objectives of this study were (1) to see if the colors red and green reflect only their own color or if they reflect to some degree all colors of the visible spectrum;

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[1]Harold C. Kulla, "Comparison of the Actual Physical Composition With Commonly Accepted Statements Concerning Color Reflected by Objects" (unpublished Master's thesis, Drake University, Des Moines, Iowa, 1959)

(2) to investigate the spectral region of each color's respective complementary color and to compare the degree of reflectance in these spectral regions for each color; (3) to present a meaningful interpretation of complementary colors and color reflection for students that are non-science majors.

I. BACKGROUND

This problem arose partially from the work of the Physical Science Course at Drake University where in addition to giving the students a basic understanding and knowledge of some general principles of science one of the main objectives is to also give the student an experience in the methods of scientific approach to problems. Regular science departments usually assume that the student will experience the methods of science when performing research for his graduate degree. The impression is given that a student cannot conduct a research project until the facts of a particular area are mastered.[1] This view is not held in its entirety by the staff of Drake's Physical Science Department. The staff feels that even though a student does not know all the facts and principles within an area of science he can still get an appreciation and feeling for the methods of science by experiencing an investi-

[1] Kulla, op. cit., p.2

gative process. The students, even though non-science majors, at the end of the physical science course are expected to attack a problem and perform an investigation in which the results are unknown to them. Many of these individual projects are performed with color for several reasons: (1) color is not a part of the regular course study; (2) the study of color arouses an interest quite easily with most people; (3) until recently text books have not treated color with very much clarity and thoroughness.[1] In view of the above, color makes an excellent choice of project work since it is very difficult for the student to find complete answers in reference books. However, the student is limited in his study because it is difficult to express his results and conclusions in a quantitative manner.

To assist the student in this problem of quantitative measurements N. M. Evers of the Drake Physical Science Department is concurrently in the process of modifying a student spectroscope to measure relative intensities of various regions of the visible spectrum. The modified spectroscope uses a photoelectric tube to scan the spectrum of an incandescent source. In the photoelectric effect the electrical current is proportional to the intensity of the incident light source. The light incident upon the photo tube excites an

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[1]*Ibid.*, p.3

electrical current through the circuit which is passed into an amplifier and from the amplifier to an ammeter. In this manner the relative intensities of a spectrum can be measured in terms of the electrical current stimulated by the varying spectral regions.

It is with this background in mind that the purpose of this study can be fully stated. Upon investigation of the complementary colors red and green the student will have at his disposal a more complete picture of complementary colors, and the reflectance of color. The student then employing the findings of this paper with the apparatus being built by Evers or another suitable apparatus will have a better interpretation of color, a method of studying color and a means to express data and conclusions more quantitatively.

II. LITERATURE

The importance of the findings of the thesis by Kulla upon this study was presented earlier in this chapter. In addition to this literature search, it was found that in 1960 B. E. Erickson, Sr. presented a thesis to Drake University which was based upon E. H. Land's work on the two color theory.[1] Erickson's work involved photographing a scene on

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E. H. Land, "Experiments in Color Vision," Scientific American, CC (May, 1959), 84-99.

black and white film through a red filter and a green filter. The positive prints were made in black and white transparencies. When the two transparencies were projected through color filters and superimposed upon a screen by two projectors the scene was reproduced in nearly full color. The intensities of the light projected through the transparencies varied according to the spectral responses of the individual filters used.[1] This study shows the red and green being separated from white light by the use of proper filters can be recombined to produce a natural color effect.

This study by Erickson, based upon E. H. Land's work on two color theory was a follow up on the three color theory by Maxwell and Helmholtz in the mid 19th Century. Maxwell's work consisted of combining light through red, green and blue filters.[2] The light re-combined through these three colored filters resulted in a scene in full color.

Further search of the literature in physics books for their view on complementary colors yielded nothing more than a definition of the term and statements saying that red and

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[1] B. E. Erickson, Sr., "Film Densities and Light Intensities of Various Colors Produced by the Land Process" (unpublished Master's thesis, Drake University, Des Moines, Iowa, 1960)

[2] F. Bello, "Astonishing New Theory of Color," <u>Fortune</u>, LIX, No. 5 (May, 1959), 144-48.

blue-green are complementary. Complementary colors are defined as "two colors that can be added or combined to obtain white."[1] "There are several pairs of colors that yield white light when added; they are called complementary colors. Yellow and blue are complementary, as are also red and blue-green."[2] Several texts also depicted reflectance curves of various colors. The search was also made in the Chemical Abstracts from 1937 to date and The Reader's Guide from 1945 to date. The only information that was of help in these sources lead to a series of four articles in periodicals dealing with E. H. Land's process which was mentioned earlier.

To obtain additional information on color, books dealing with color entirely were investigated. It was found that color does not stop with the physics of light, wavelengths and intensities of radiant energy. The problem of color is also connected with the brain and its attached nervous system. As one source states; "The eye upon being stimulated by light sends impulses to the brain. Color is a matter of mental judgment, association and emotional response."[3]

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[1]F. Sears and M. Zemansky, University Physics (Reading, Massachusetts: Addison-Wesley Pub. Co. Inc., 1957), p. 827.

[2]E. Hausman-E. Slack, Physics (Princeton, New Jersey: D. Van Nostrand Co. Inc., 1959), p. 598.

[3]Faber Birren, Color Dimension (Chicago: Crimson Press, 1944)

This statement as many similar statements from other sources point out that in seeing color there is a physiological and psychological process. The line between the two is very thin, but at some point there is the transition. The eye separates the colors, but our mind forms the perceptions of space, color, shades and hues. Many books dealing with color and color mixing were investigated, but discussed pigments, color mixing and matching. An example of these is a book by William J. Miskella, Practical Color Simplified.[1]

The search of the literature yielded much information concerning paints, dyes, color mixing, the physiology and psychology of color, but was of little help in finding essential characteristics of complementary colors.

In view of the fact that red and green are considered to be complementary, still, two questions remain. (1) What is there that is essentially characteristic to the various shades of red and green? (2) Why is it that they can be combined to produce a white sensation?

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[1]William J. Miskella, Practical Color Simplified (Chicago: Finishing Research Laboratories, Inc., 1928)

CHAPTER II

I. METHOD OF RESEARCH

Since the literature did not offer answers to the questions raised in the preceeding chapter, it was decided that an analysis of the complementary colors red and green should be made.

Six samples each of red and green paper in various shades were obtained. The reds varied from brilliant red to a blue red. The greens varied from a blue-green to dark green to yellow green. The various shades were chosen with the hope of finding a characteristic common to all the varying shades of each color. All of the samples were taken from the same issue of a magazine so that the texture can be assumed to be the same.

The analysis of these samples was made with the use of the Beckman Spectrophotometer (model DU) using the reflectance attachment. With this instrument individual wavelengths of light can be obtained and directed upon a white standard and then on the sample to be studied. At each wavelength setting the light is directed upon the white standard and the reflectance scale is adjusted to read 100 per cent. The sample is then moved into the beam of light. The light reflected by the sample is directed to a photoelectric tube where a small electric current is generated. This current is amplified and registered upon a galvanometer. The more light there is reflected, the more current there will from the phototube. When the sample is placed into the light beam after having adjusted the standard's current reading to 100 per cent the galvanometer's reading will change. This is a result of the difference in the current from the phototube due to the varying reflecting qualities of the standard and sample. To obtain the per cent of light reflected by the sample the reflectance scale is adjusted until the galvanometer is zeroed. The percentage of light reflected by the sample as compared to the white standard is then automatically recorded on the instrument.

II. ANALYSIS OF COLORS

The spectral region that was investigated for all the colored objects ranged from 350 to 750 millimicrons. Four readings of each sample were made to check the reproducibility of the spectrophotometer. The majority of the readings were within 0.2 per cent of the mean value. The largest deviation which occurred was 1.3 per cent. Two wavelengths were randomly chosen for each sample for which the standard deviation was determined. Most of the deviations were o.11 and 0.12. The largest standard deviation was 0.35. The mean standard deviation was 0.15.

The data recorded during the investigation are given in the Tables I through XII. The results are shown graphically in Figures 1 through 14.

Table XIII contains data showing the wavelengths at which the maximum and minimum reflectances occur for each of the samples. Figures 13 and 14 are composite graphs containing the reflectance curves of all the samples. These graphs give an immediate overall view of the maximum and minimum reflectance for all samples in their respective spectral regions.

TABLE I

PER CENT OF LIGHT REFLECTED FOR THE GIVEN WAVELENGTH FROM THE GREEN SAMPLE NUMBER ONE

Wavelength in MU	Trial One	Trial Two	Trial Three	Trial Four	Mean
350	2.7	2.5	2.6	2.8	2.7
375	4.2	4.2	4.1	4.4	4.2
400	6.2	6.1	6.3	6.4	6.3
425	6.0	5.8	5.8	6.0	5.9
450	6.8	6.7	6.7	6.9	6.8
475	6.5	6.4	6.6	6.5	6.5
500	17.2	17.2	17.1	17.4	17.3
525	33.2	33.0	33.3	33.1	33.1
550	22.8	22.5	22.6	22.5	22.6
575	12.1	12.1	12.2	12.4	12.2
600	9.4	9.7	9.5	9.2	9.5
625	8.2	8.5	8.4	8.5	8.4
650	8.3	8.5	8.3	8.4	8.4
675	11.1	11.0	11.1	11.1	11.1
700	12.7	13.0	12.9	13.1	13.0
725	13.7	14.0	13.5	13.8	13.8
750	25.0	25.5	25.4	25.3	25.2

TABLE II

PER CENT OF LIGHT REFLECTED FOR THE GIVEN WAVELENGTH FROM THE GREEN SAMPLE NUMBER TWO

Wavelength in MU	Trial One	Trial Two	Trial Three	Trial Four	Mean
350	2.9	2.7	2.9	3.0	2.9
375	4.7	4.8	4.4	4.8	4.7
400	6.8	6.8	6.7	6.9	6.8
425	6.0	5.8	6.1	6.1	6.0
450	6.4	6.6	6.7	6.4	6.5
475	8.0	8.3	8.1	8.4	8.2
500	15.4	15.7	15.5	15.8	15.6
525	25.3	25.5	25.6	25.4	25.4
550	16.3	16.4	16.5	16.4	16.4
575	9.0	9.1	8.9	9.3	9.1
600	8.6	8.2	8.4	8.8	8.5
625	7.7	7.5	7.4	7.7	7.6
650	7.2	7.0	7.0	7.4	7.2
675	10.0	9.8	10.1	10.2	10.0
700	11.0	11.3	11.2	11.4	11.2
725	10.7	10.6	10.6	10.5	10.6
750	22.0	21.8	22.1	21.9	22.0

TABLE III

PER CENT OF LIGHT REFLECTED FOR THE GIVEN WAVELENGTH FROM THE GREEN SAMPLE NUMBER THREE

Wavelength in MU	Trial One	Trial Two	Trial Three	Trial Four	Mean
350	2.3	2.2	2.2	2.4	2.2
375	7.1	7.3	7.1	7.2	7.2
400	8.4	8.3	8.4	8.2	8.3
425	8.2	8.1	8.4	8.4	8.3
450	9.0	9.0	9.1	9.1	9.1
475	10.0	10.1	9.8	10.1	10.0
500	18.8	18.6	18.7	18.8	18.7
525	32.8	33.0	33.1	32.9	33.0
550	24.0	23.4	23.7	23.9	23.7
575	13.6	13.5	13.2	13.6	13.5
600	12.0	11.9	11.8	12.1	12.0
625	10.4	10.5	10.4	10.4	10.4
650	12.0	12.0	12.2	12.1	12.1
675	15.0	15.1	14.8	15.0	15.0
700	16.3	16.2	16.5	16.7	16.4
725	17.8	17.7	17.9	18.0	17.8
750	33.0	31.8	32.7	33.1	32.7

TABLE IV

PER CENT OF LIGHT REFLECTED FOR THE GIVEN WAVELENGTH FROM THE GREEN SAMPLE NUMBER FOUR

Wavelength in MU	Trial One	Trial Two	Trial Three	Trial Four	Mean
350	1.5	1.8	1.7	1.7	1.7
375	3.0	3.2	3.3	3.5	3.3
400	4.0	4.3	4.2	4.4	4.2
425	6.0	5.5	5.3	5.2	5.5
450	5.0	4.8	5.1	5.1	5.0
475	6.0	5.8	5.9	5.8	5.9
500	11.8	12.0	11.8	11.7	11.8
525	22.2	21.7	21.5	21.6	21.8
550	14.5	13.8	14.5	14.4	14.3
575	8.8	9.1	8.7	8.9	8.9
600	6.0	5.8	6.1	6.0	6.0
625	5.2	5.3	5.4	5.4	5.3
650	6.0	6.5	6.3	6.5	6.3
675	7.5	7.7	7.8	7.5	7.6
700	8.5	8.3	8.6	8.4	8.5
725	7.5	7.5	7.4	7.4	7.5
750	18.1	18.0	18.3	18.1	18.1

TABLE V

PER CENT OF LIGHT REFLECTED FOR THE GIVEN WAVELENGTH FROM THE GREEN SAMPLE NUMBER FIVE

Wavelength in MU	Trial One	Trial Two	Trial Three	Trial Four	Mean
350	17.2	17.0	17.3	17.2	17.2
375	26.2	26.3	25.9	26.2	26.2
400	26.8	26.8	27.1	27.0	26.9
425	27.6	27.5	27.8	27.4	27.6
450	31.8	31.6	31.5	31.5	31.6
475	38.0	37.9	38.2	38.2	38.0
500	55.9	57.2	57.4	57.1	56.8
525	68.0	66.6	66.5	66.5	66.7
550	60.8	60.8	60.6	60.5	60.7
575	53.8	53.5	53.4	53.9	53.6
600	48.3	47.9	48.0	48.1	48.0
625	44.6	45.0	44.9	44.8	44.8
650	44.8	45.0	45.1	44.9	44.8
675	48.6	48.6	48.6	48.6	48.6
700	62.2	62.1	62.2	62.2	62.2
725	71.0	71.1	71.1	71.2	71.1
750	70.5	70.6	70.6	70.5	70.6

TABLE VI

PER CENT OF LIGHT REFLECTED FOR THE GIVEN
WAVELENGTH FROM THE GREEN SAMPLE
NUMBER SIX

Wavelength in MU	Trial One	Trial Two	Trial Three	Trial Four	Mean
350	3.2	3.7	3.3	3.2	3.4
375	4.8	4.9	4.8	4.8	4.8
400	7.8	8.0	8.1	7.9	8.0
425	8.1	8.2	8.2	8.1	8.2
450	8.0	8.3	7.8	7.9	8.0
475	9.0	9.2	9.1	9.4	9.2
500	17.1	17.2	18.0	17.3	17.4
525	34.4	35.1	34.7	34.5	34.6
550	23.2	23.5	23.7	23.6	23.5
575	8.9	8.8	9.1	9.1	9.0
600	10.5	10.5	10.7	10.5	10.5
625	9.1	9.2	9.4	9.2	9.2
650	9.8	10.0	10.1	10.1	10.0
675	13.7	13.6	13.8	13.7	13.8
700	15.0	15.4	15.3	15.4	15.3
725	16.1	16.2	16.4	16.2	16.2
750	28.1	27.9	28.3	27.9	28.1

TABLE VII

PER CENT OF LIGHT REFLECTED FOR THE GIVEN WAVELENGTH FROM THE RED SAMPLE NUMBER ONE

Wavelength in MU	Trial One	Trial Two	Trial Three	Trial Four	Mean
350	2.5	2.7	2.5	2.6	2.6
375	7.5	7.3	7.3	7.4	7.4
400	7.5	7.2	7.4	7.3	7.4
425	6.8	7.0	6.8	7.1	6.9
450	4.0	4.1	4.2	4.0	4.1
475	4.0	4.2	4.1	4.0	4.1
500	3.0	3.1	3.1	3.2	3.1
525	3.5	3.5	3.5	3.4	3.5
550	3.5	3.4	3.3	3.4	3.4
575	3.3	2.5	3.1	2.9	3.0
600	24.2	24.2	24.1	24.0	24.1
625	37.0	37.3	37.2	37.4	37.2
650	40.0	40.2	40.1	40.0	40.1
675	42.4	42.5	42.4	42.3	42.3
700	43.1	43.1	43.3	43.2	43.2
725	42.5	42.6	42.5	42.4	42.5
750	46.3	46.4	46.6	46.5	46.5

TABLE VIII

PER CENT OF LIGHT REFLECTED FOR THE GIVEN WAVELENGTH FROM THE RED SAMPLE NUMBER TWO

Wavelength in MU	Trial One	Trial Two	Trial Three	Trial Four	Mean
350	3.8	3.5	3.6	3.6	3.6
375	5.2	5.0	5.1	5.2	5.1
400	5.0	4.9	5.1	5.0	5.0
425	3.7	3.6	3.7	3.7	3.7
450	3.4	3.3	3.4	3.2	3.3
475	3.5	3.7	3.4	3.6	3.6
500	3.0	2.8	3.1	3.0	3.0
525	3.5	3.8	3.7	3.6	3.7
550	2.9	1.6	1.7	1.8	1.8
575	25.3	25.6	25.5	25.5	25.5
600	48.2	48.6	48.4	48.5	48.5
625	46.0	46.0	46.3	46.1	46.1
650	46.0	46.2	46.2	46.1	46.1
675	27.3	27.4	27.4	27.3	27.4
700	49.7	50.0	49.8	50.2	50.0
725	49.2	49.2	49.0	49.1	49.1
750	52.8	52.7	53.0	52.8	52.8

TABLE IX

PER CENT OF LIGHT REFLECTED FOR THE GIVEN WAVELENGTH FROM THE RED SAMPLE NUMBER THREE

Wavelength in MU	Trial One	Trial Two	Trial Three	Trial Four	Mean
350	13.6	13.6	13.5	13.4	13.5
375	29.5	30.0	29.8	29.7	29.7
400	30.2	30.0	30.1	30.1	30.1
425	30.0	30.0	30.0	30.1	30.0
450	26.4	26.0	26.3	26.1	26.1
475	13.8	14.5	14.1	14.2	14.2
500	5.3	5.3	5.2	5.5	5.3
525	4.3	4.4	4.7	4.4	4.5
550	1.5	1.7	1.7	1.7	1.7
575	2.3	2.3	2.1	2.2	2.2
600	40.0	39.8	39.9	40.2	39.9
625	64.7	66.0	65.8	65.4	65.5
650	68.6	69.2	68.7	68.9	68.8
675	70.1	70.5	70.3	70.5	70.4
700	71.4	71.7	71.2	71.5	71.4
725	71.4	71.5	71.5	71.5	71.5
750	71.1	70.8	71.0	71.0	71.0

TABLE X

PER CENT OF LIGHT REFLECTED FOR THE GIVEN WAVELENGTH FROM THE RED SAMPLE NUMBER FOUR

Wavelength in MU	Trial One	Trial Two	Trial Three	Trial Four	Mean
350	7.0	6.7	7.5	7.2	7.1
375	10.8	10.2	10.5	10.4	10.5
400	11.2	10.7	11.1	10.9	11.0
425	10.5	9.9	10.3	10.2	10.2
450	10.0	9.7	10.1	9.8	9.9
475	8.0	8.3	8.1	8.2	8.2
500	8.8	8.5	8.6	8.5	8.6
525	7.5	7.1	7.3	7.4	7.3
550	8.5	8.2	8.3	8.4	8.3
575	7.0	7.2	7.2	7.1	7.1
600	38.5	37.7	37.8	38.3	38.0
625	49.5	48.9	49.3	49.1	49.3
650	51.0	50.2	51.2	50.8	51.0
675	54.0	53.8	54.0	54.1	53.8
700	54.0	53.8	53.8	54.0	54.9
725	54.4	54.6	54.6	54.5	54.6
750	55.5	56.1	55.8	55.7	55.7

TABLE XI

PER CENT OF LIGHT REFLECTED FOR THE GIVEN WAVELENGTH FROM THE RED SAMPLE NUMBER FIVE

Wavelength in MU	Trial One	Trial Two	Trial Three	Trial Four	Mean
350	8.7	8.5	8.8	8.5	8.6
375	15.4	15.5	15.4	15.5	15.5
400	14.0	14.0	14.3	14.1	14.1
425	14.0	14.1	14.4	14.3	14.2
450	17.0	17.2	17.4	17.2	17.2
475	15.0	15.0	15.2	15.1	15.1
500	15.0	15.1	15.2	15.4	15.2
525	21.3	21.4	21.1	21.6	21.4
550	17.5	17.5	17.3	17.7	17.5
575	16.8	16.8	16.9	17.1	16.9
600	50.0	50.1	50.4	50.4	50.2
625	50.0	50.1	50.3	50.1	50.1
650	50.0	50.0	50.1	50.1	50.1
675	50.2	50.2	50.4	50.2	50.2
700	50.2	50.1	50.2	50.1	50.2
725	50.1	50.1	50.1	50.2	50.1
750	50.0	50.2	50.1	50.0	50.1

TABLE XII

PER CENT OF LIGHT REFLECTED FOR THE GIVEN WAVELENGTH FROM THE RED SAMPLE NUMBER SIX

Wavelength in MU	Trial One	Trial Two	Trial Three	Trial Four	Mean
350	3.0	3.1	2.9	3.2	3.1
375	8.8	8.7	8.8	8.8	8.8
400	8.3	8.7	8.4	8.4	8.4
425	5.0	5.4	5.1	5.3	5.2
450	8.1	8.4	8.0	8.1	8.2
475	5.7	5.9	5.6	5.7	5.7
500	5.8	6.1	5.9	6.0	6.0
525	3.5	3.3	3.5	3.7	3.5
550	4.8	4.7	4.4	4.5	4.6
575	3.0	2.9	2.9	3.1	3.0
600	28.8	28.7	29.1	28.8	28.9
625	42.0	41.8	42.2	41.8	42.0
650	43.5	43.8	44.1	43.8	43.8
675	45.4	45.5	45.6	45.5	45.5
700	45.0	44.9	45.4	44.8	45.0
725	45.4	45.6	45.6	45.7	45.5
750	49.5	50.1	50.0	49.7	49.8

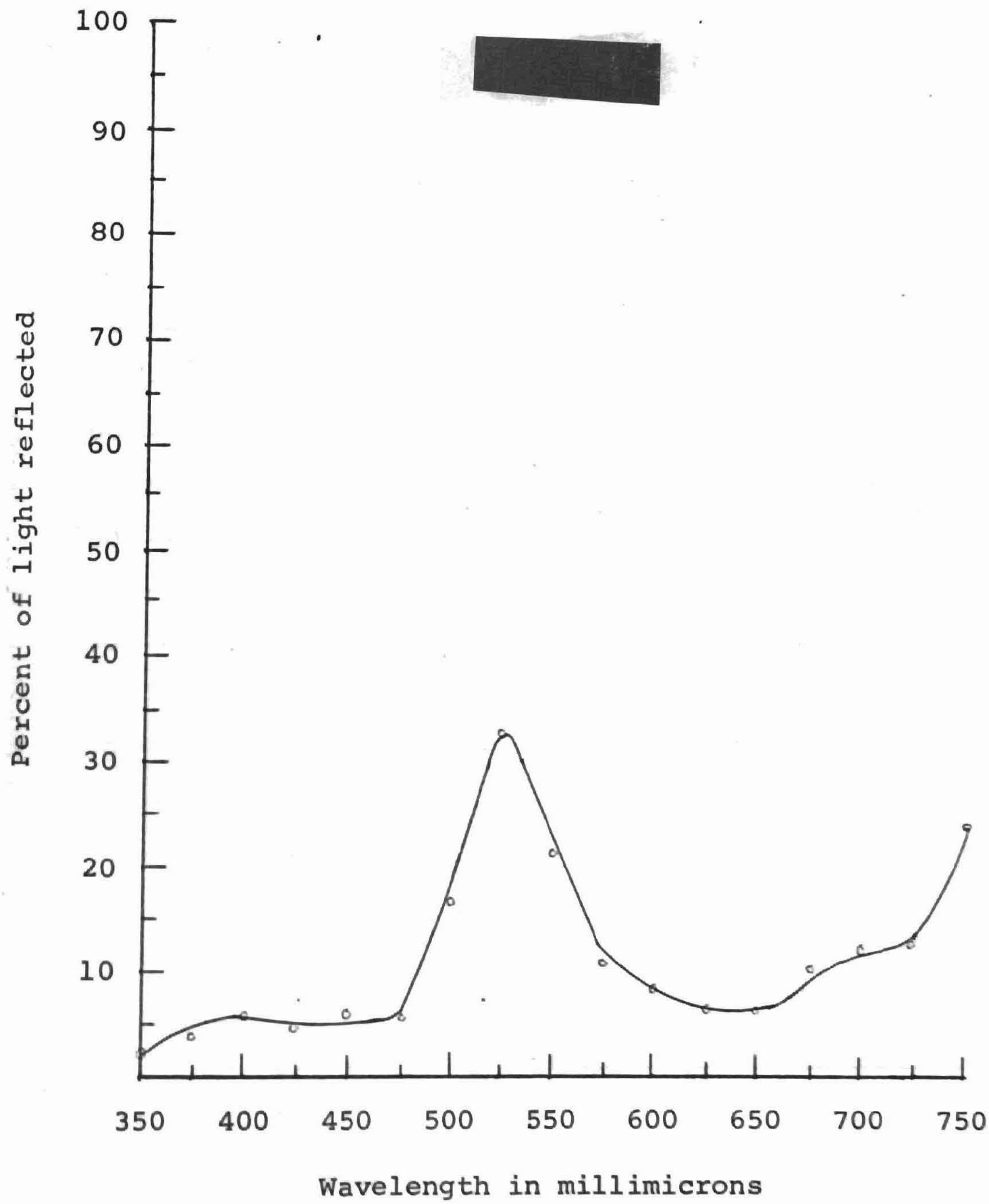

Figure 1. The percentage of light reflected from the green sample number one plotted against the wavelength of light.

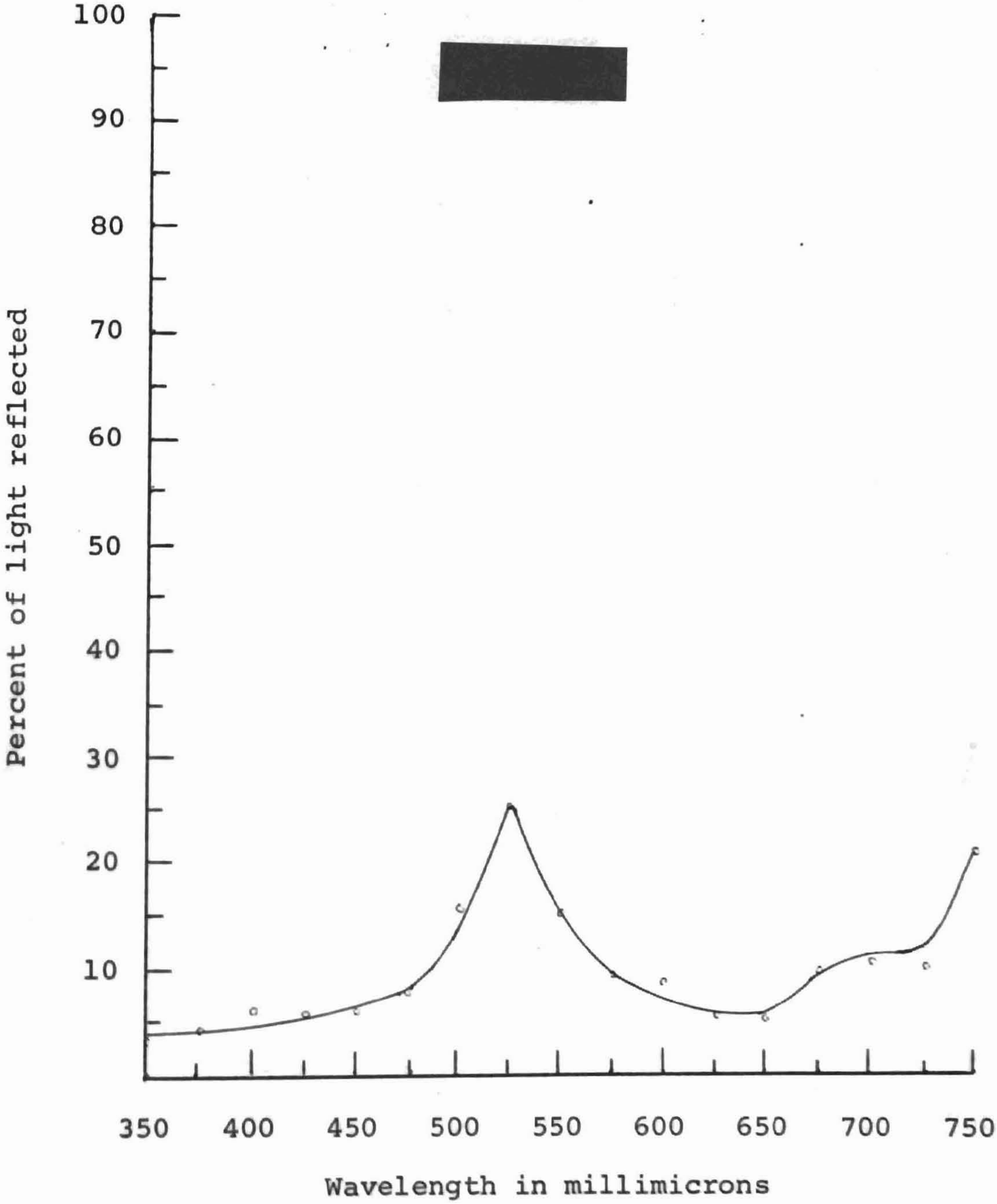

Figure 2. The percentage of light reflected from the green sample number two plotted against the wavelength of light.

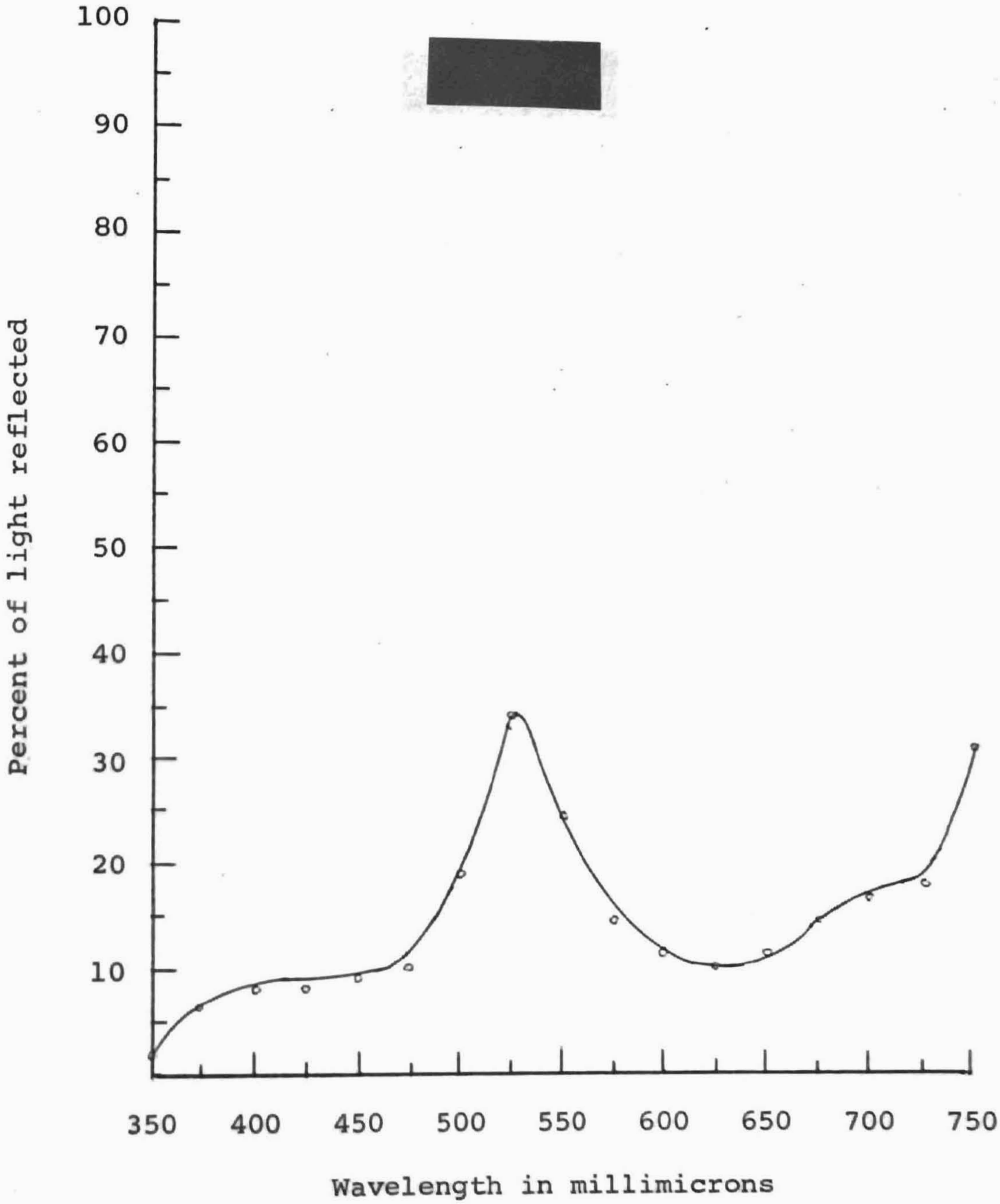

Figure 3. The percentage of light reflected from the green sample number three plotted against the wavelength of light.

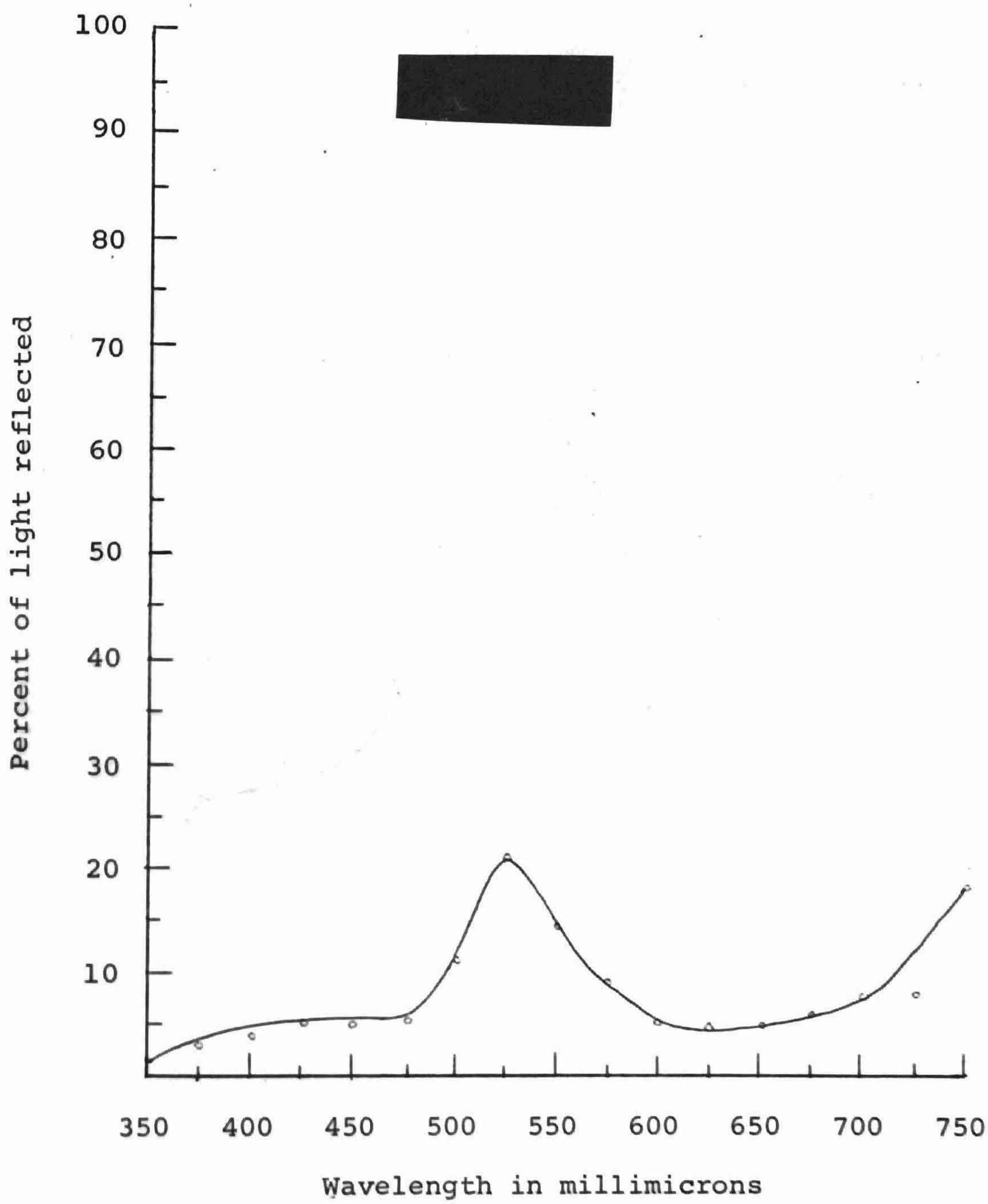

Figure 4. The percentage of light reflected from the green sample number four plotted against the wavelength of light.

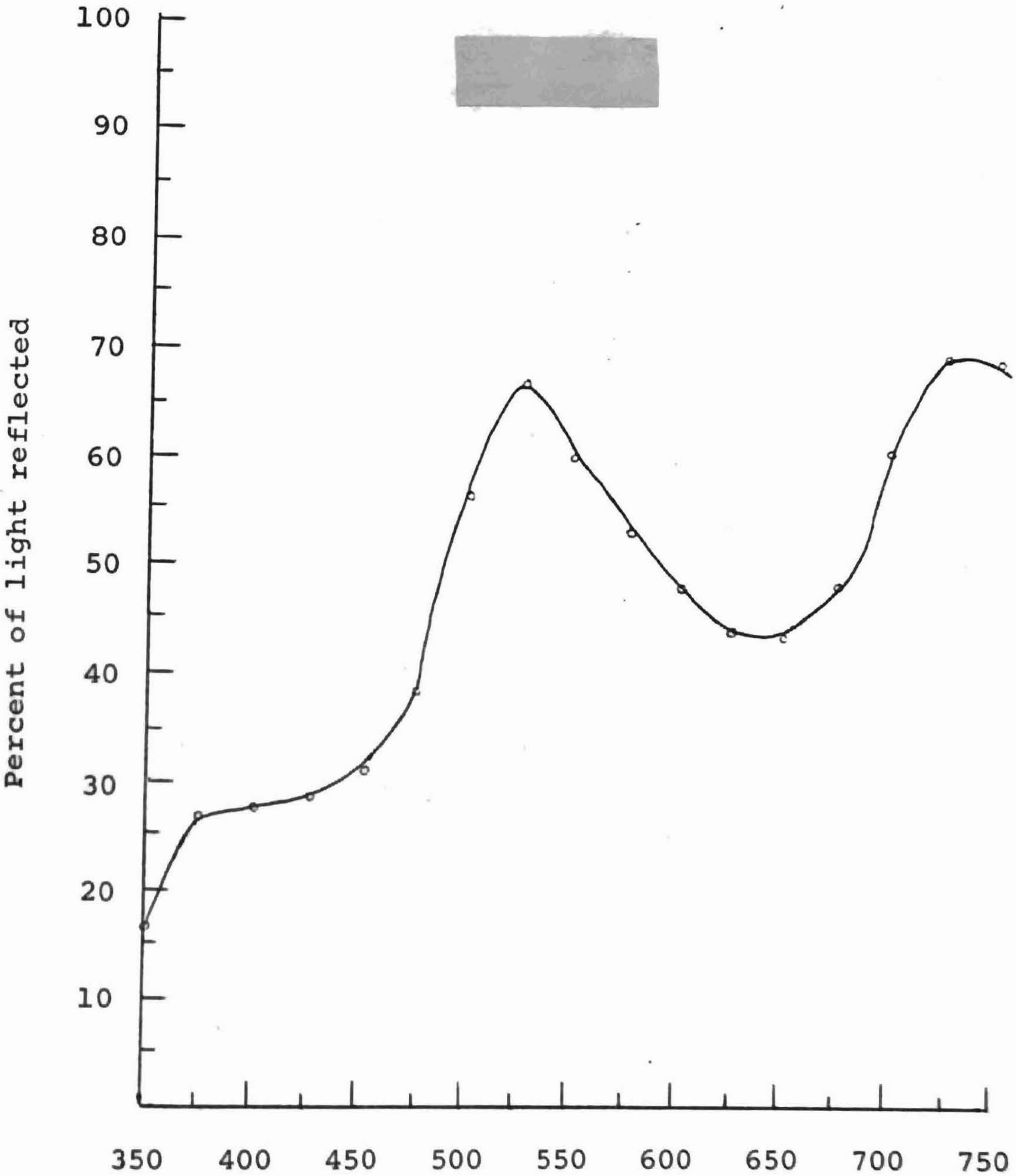

Figure 5. The percentage of light reflected from the green sample number five plotted against the wavelength of light.

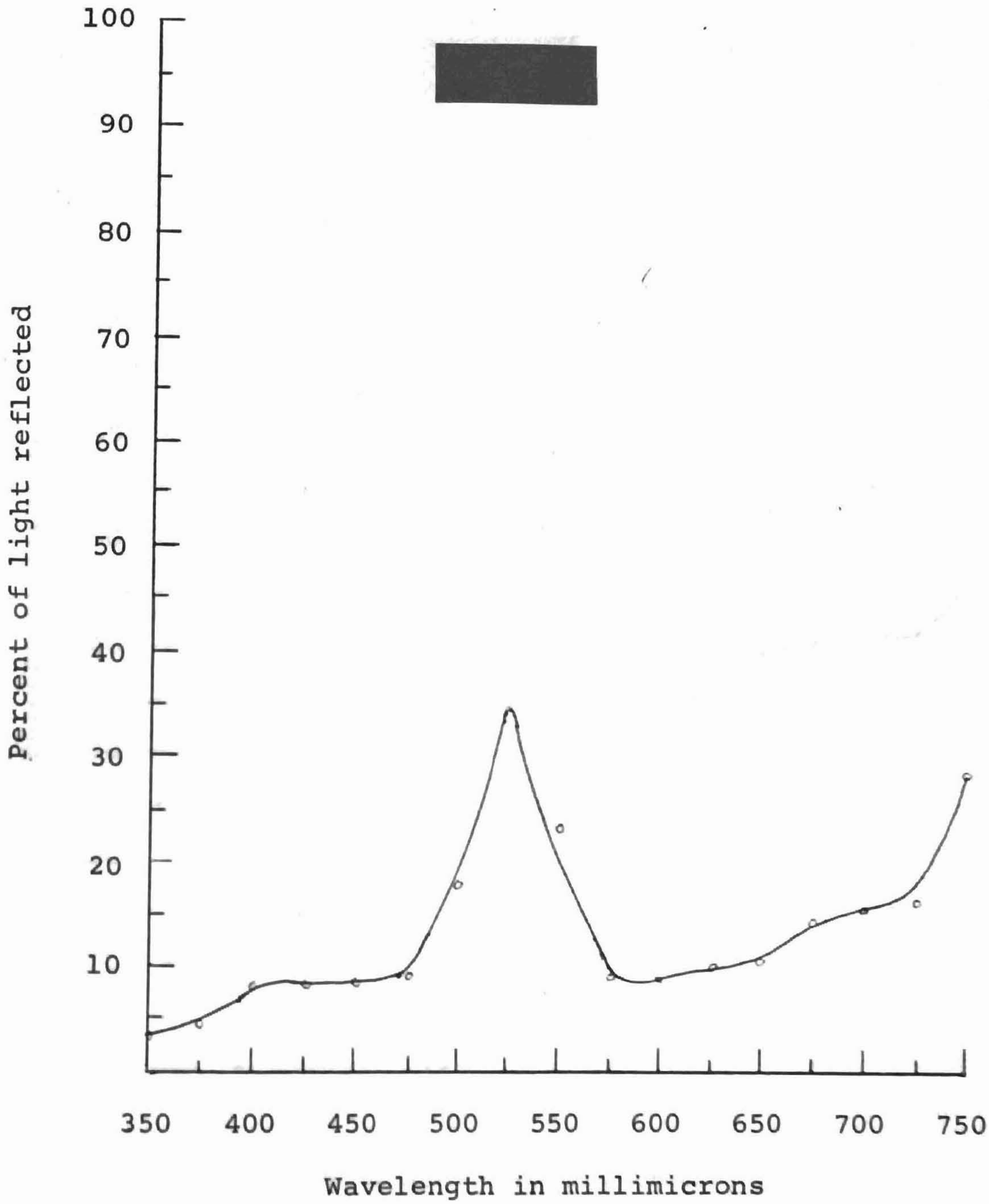

Figure 6. The percentage of light reflected from the green sample number six plotted against the wavelength of light.

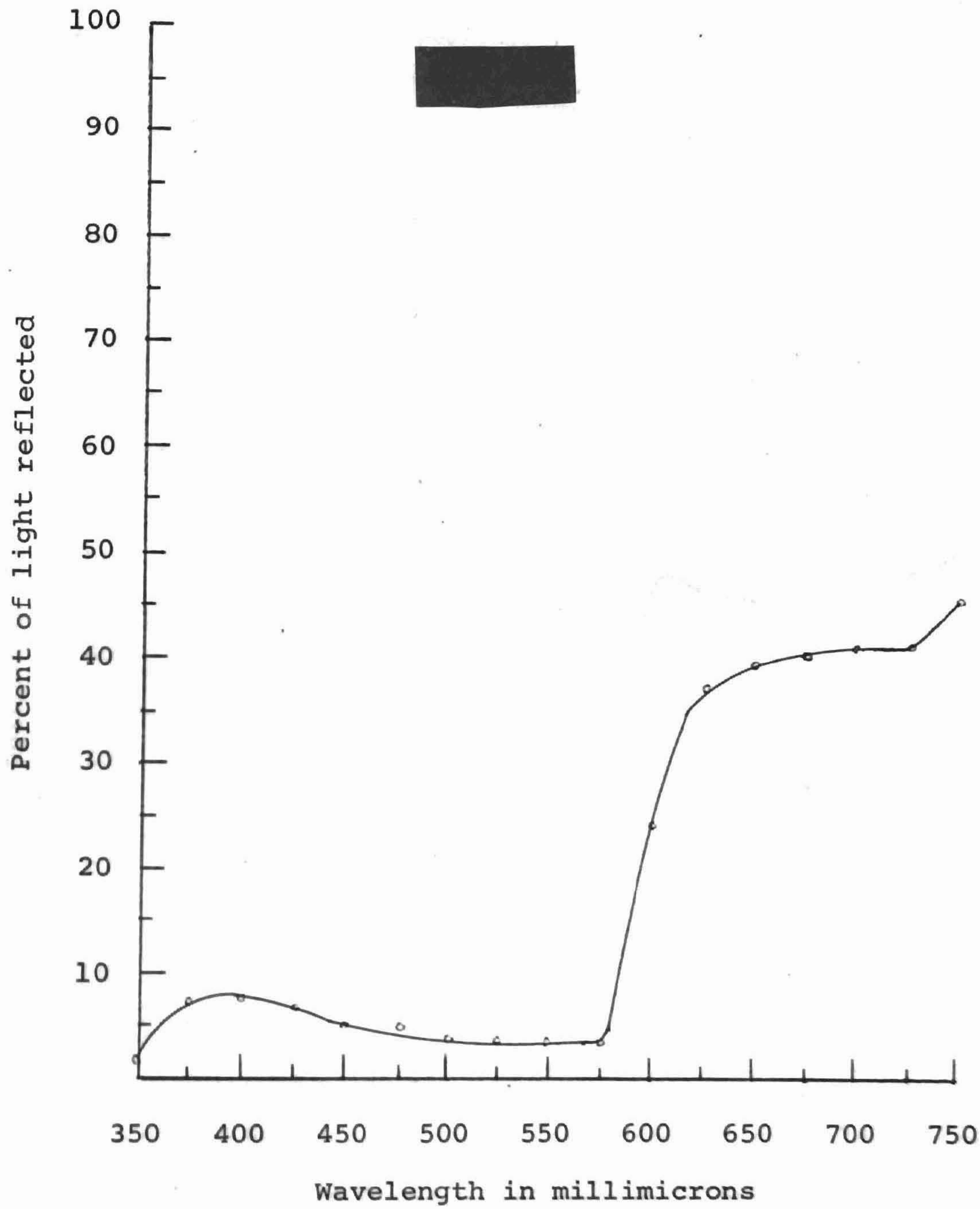

Figure 7. The percentage of light reflected from the red sample number one plotted against the wavelength of light.

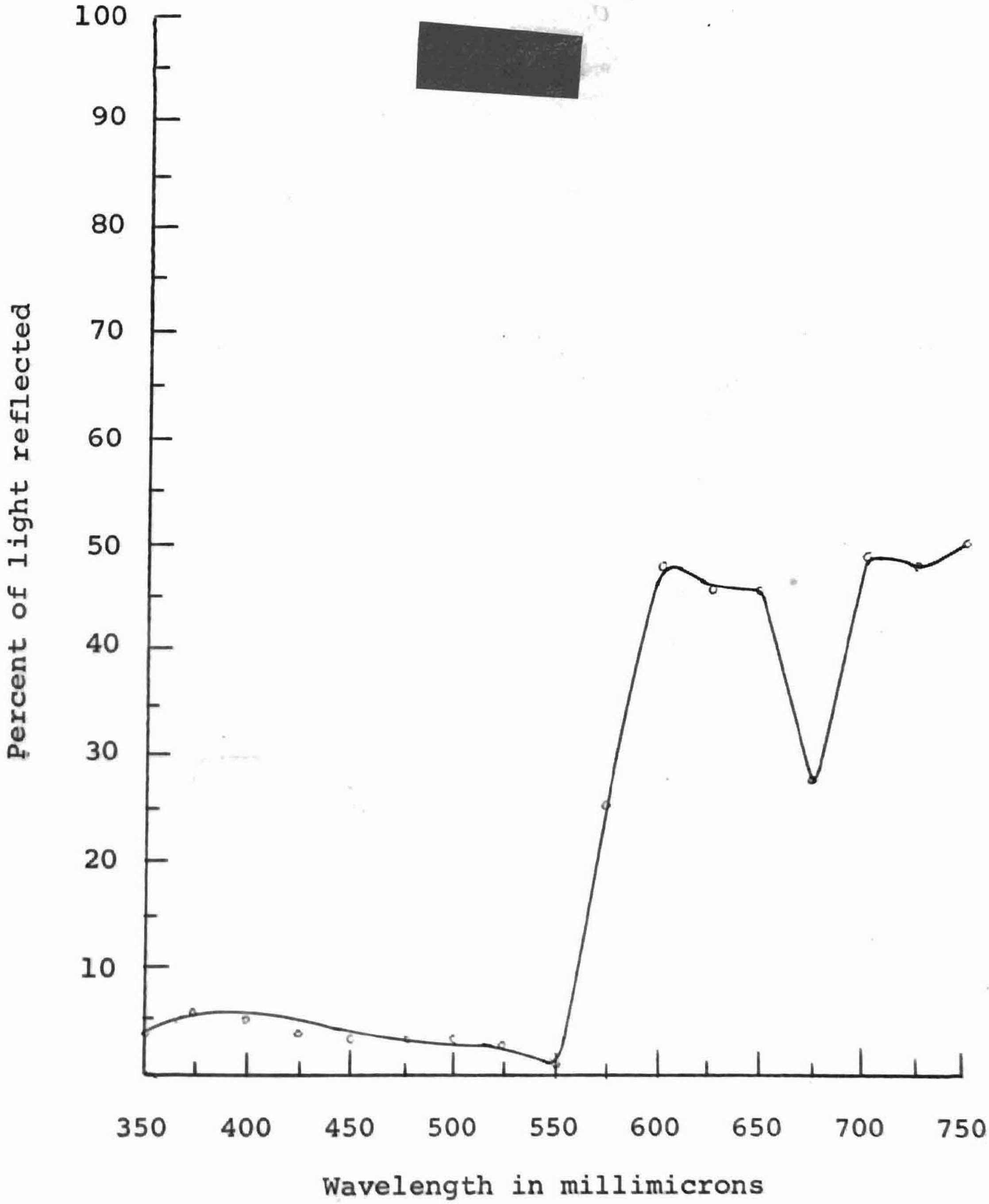

Figure 8. The percentage of light reflected from the red sample number two plotted against the wavelength of light.

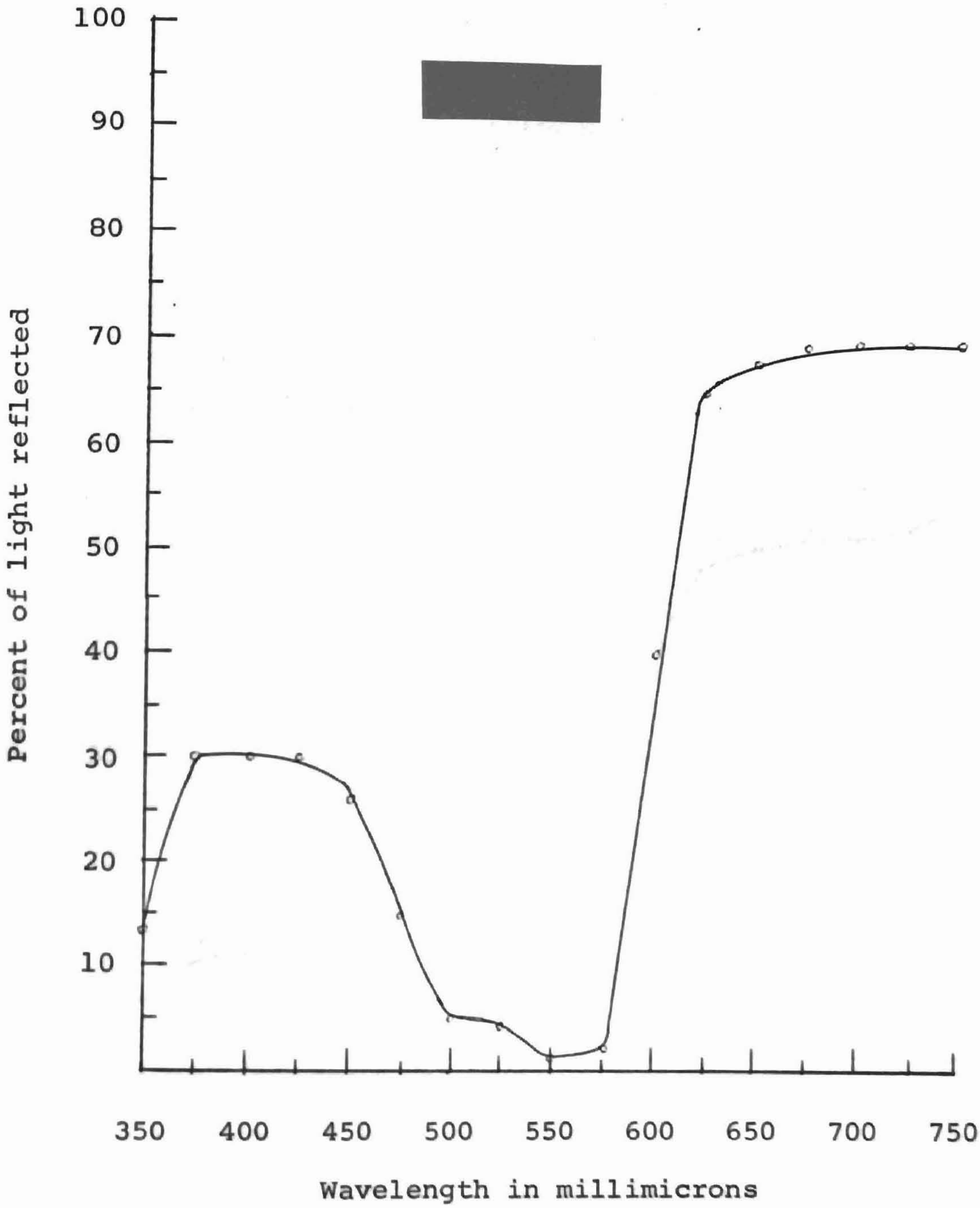

Figure 9. The percentage of light reflected from the red sample number three plotted against the wavelength of light.

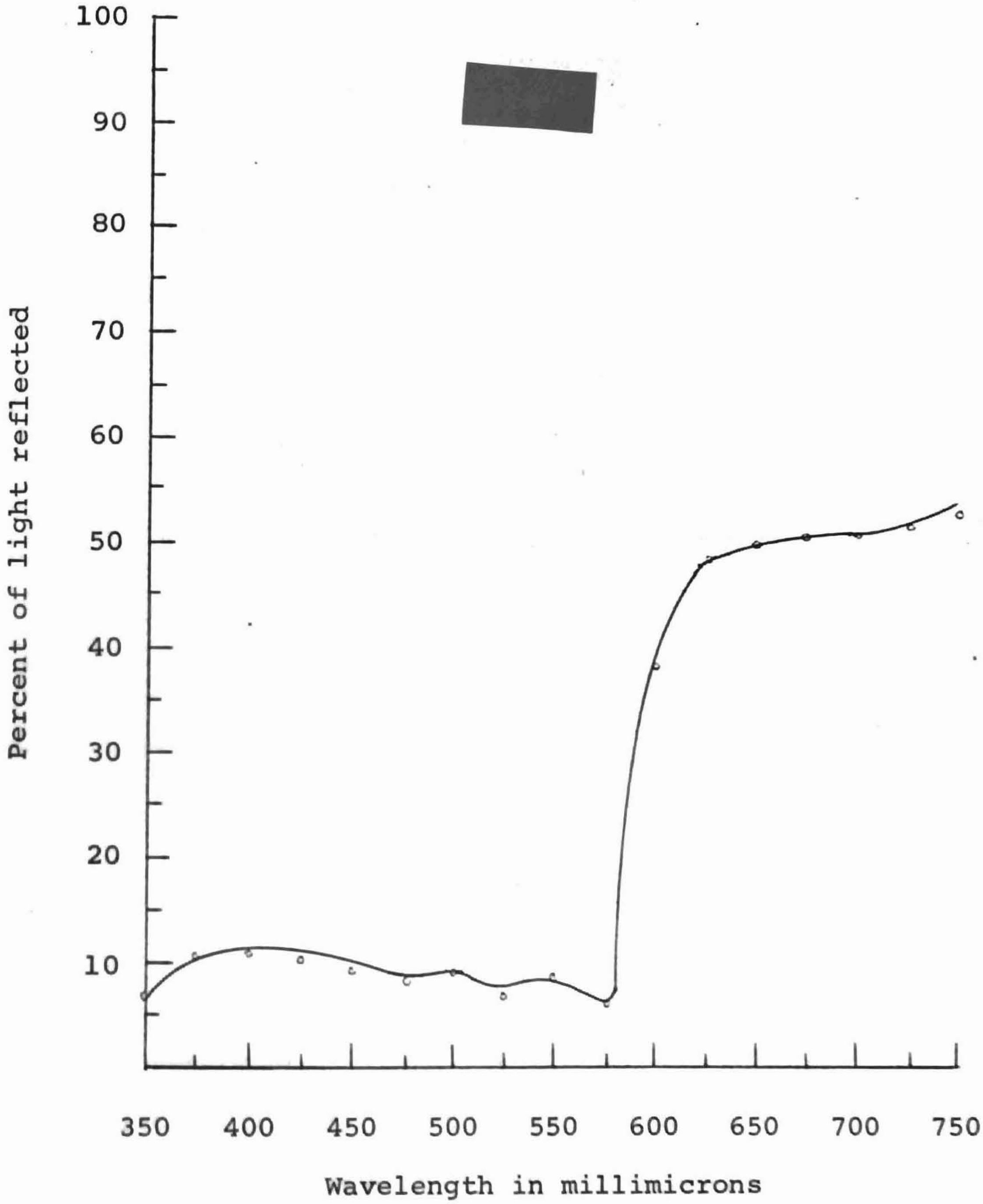

Figure 10. The percentage of light reflected from the red sample number four plotted against the wavelength of light.

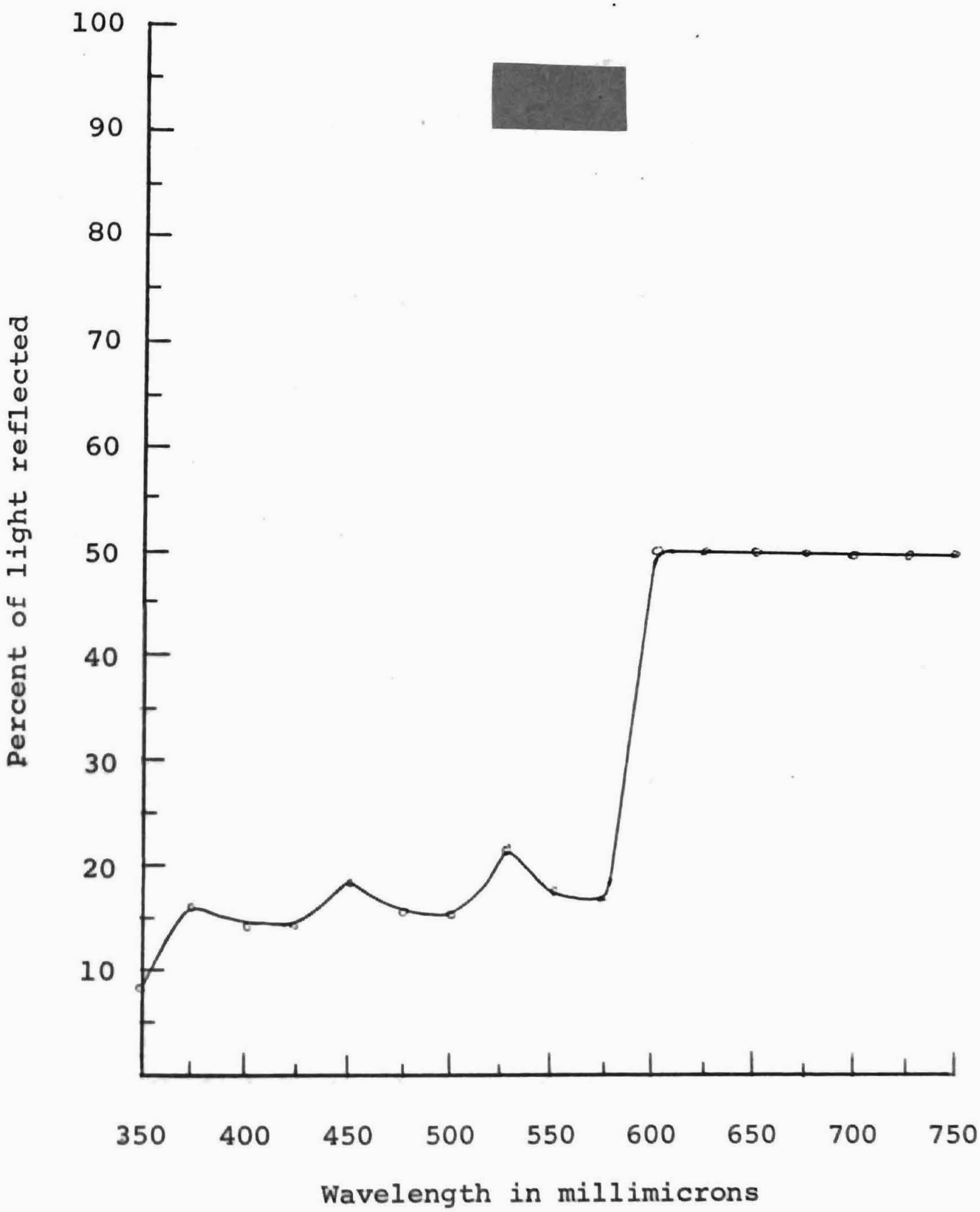

Figure 11. The percentage of light reflected from the red sample number five plotted against the wavelength of light.

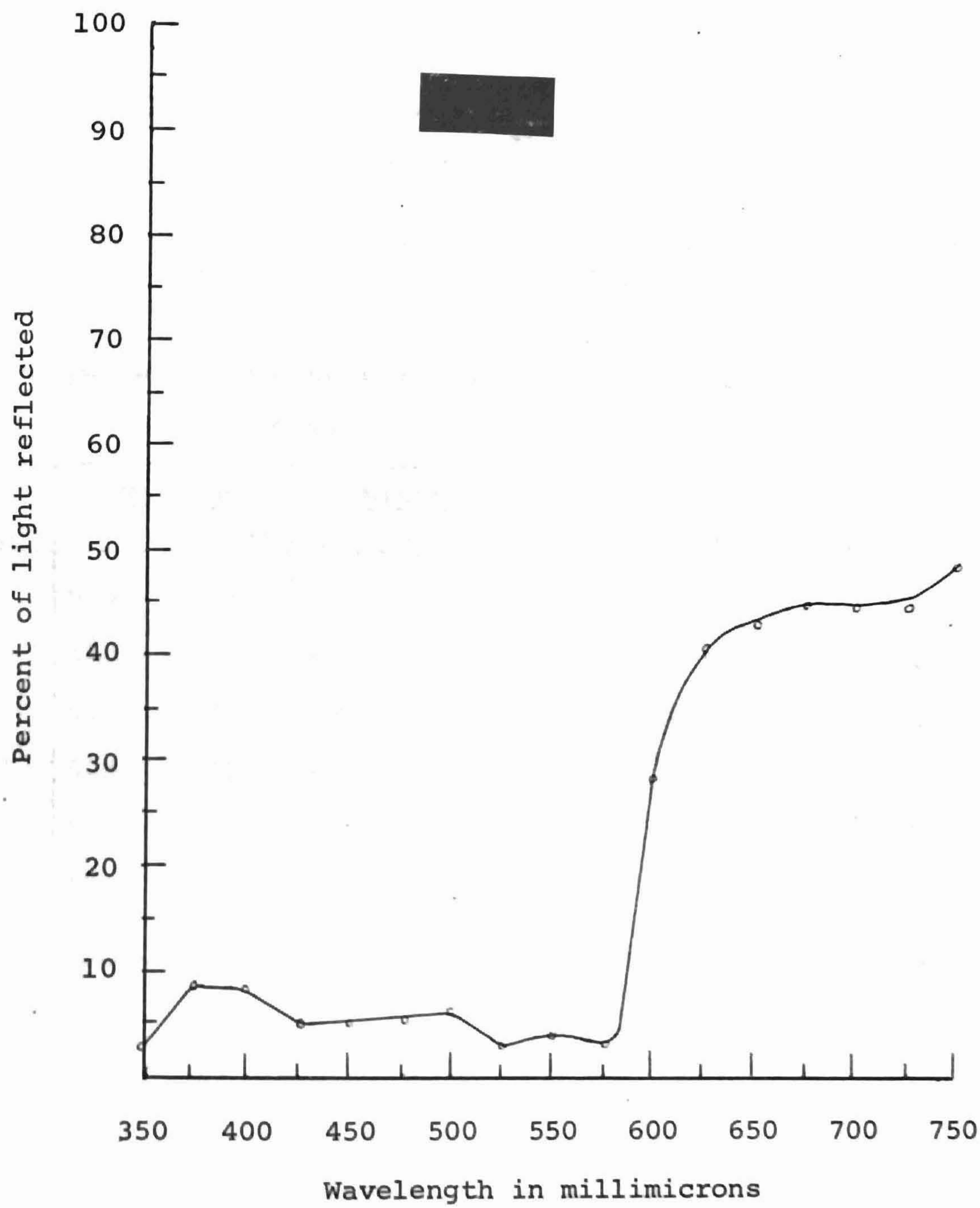

Figure 12. The percentage of light reflected from the red sample number six plotted against the wavelength of light.

TABLE XIII

MAXIMUM AND MINIMUM VALUES OF WAVELENGTHS AND PER CENT OF LIGHT REFLECTED BY ALL SAMPLES

	GREEN				RED			
	Maximum		Minimum		Maximum		Minimum	
Sample	x	per cent	x	per cent	x	per cent	x	per cent
1	525	33	635	7	725	42	525	4
2	525	25	650	4	725	50	550	2
3	525	33	625	10	725	67	550	2
4	525	22	625	5	725	52	575	5
5	525	66	625	43	725	50	500	15
6	525	36	600	9	725	50	525	25

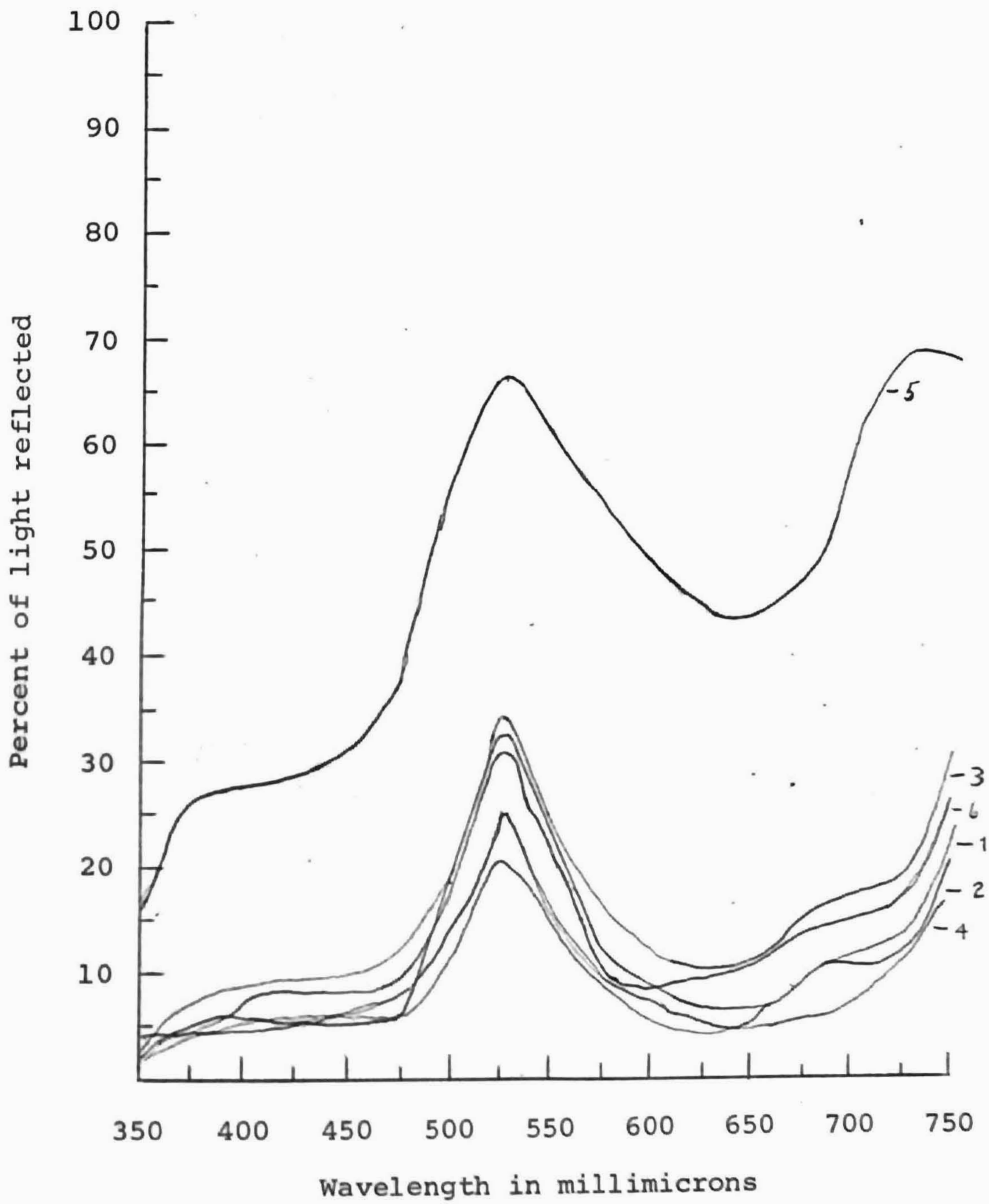

Figure 13. The percentage of light reflected from the green samples plotted against the wavelength of light.

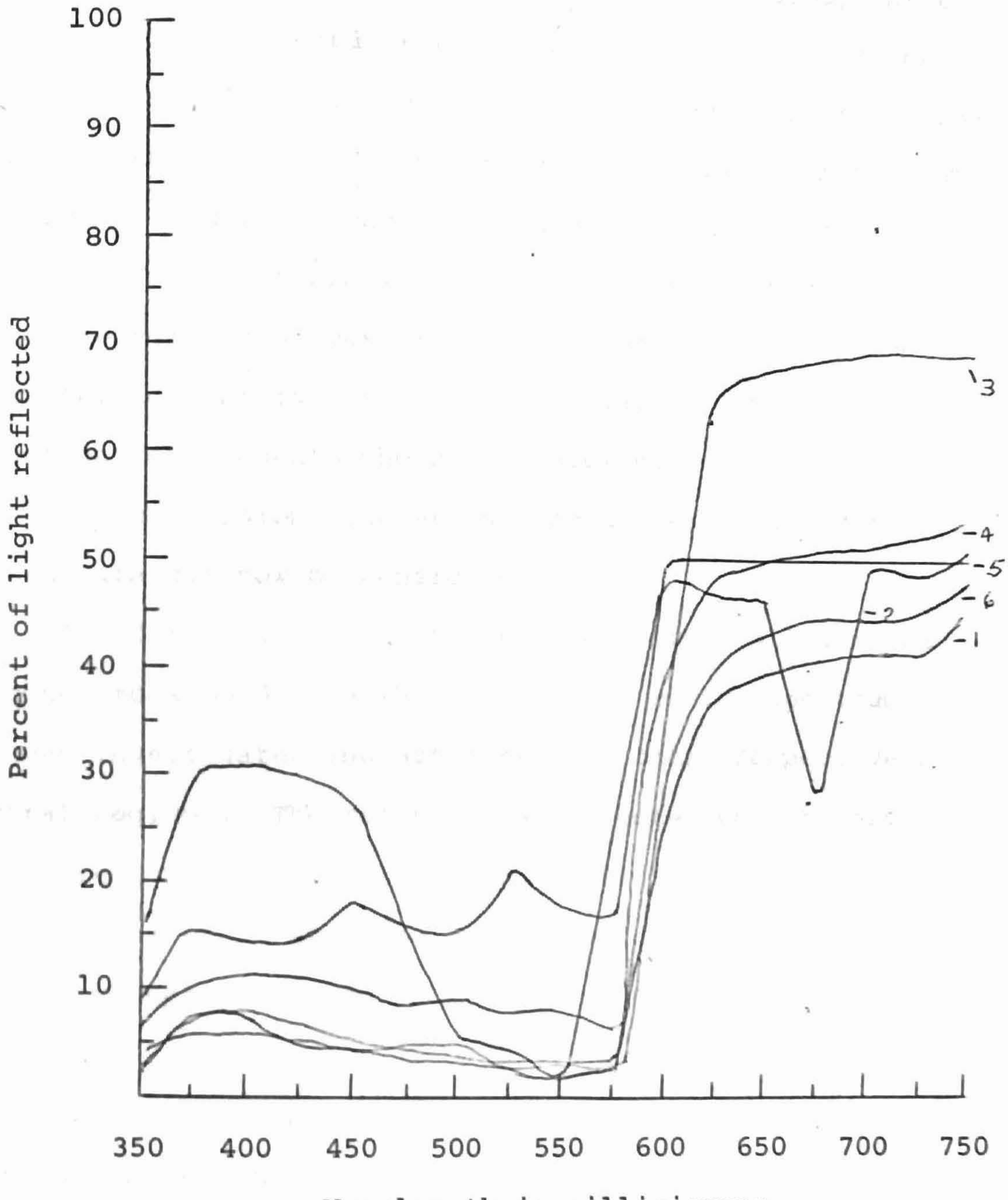

Figure 14. The percentage of light reflected from the red samples plotted against the wavelength of light.

CHAPTER III

In the discussion of the purpose of this study three questions were presented: (1) To see if the colors red and green reflect only their own color or if they reflect to some degree all colors of the visible spectrum; (2) to investigate the spectral region of each color and its complementary color in order to see if there is something essentially characteristic to the various shades of red and green; (3) to present a meaningful interpretation of complementary colors and color reflection for students who are non-science majors.

The conclusions concerning these questions and the related data can now be considered.

The first conclusion to be made is that all samples reflected to some degree through out the entire spectrum that was investigated and not merely in their respective spectral regions. The red samples reflected very highly in the red region but reflected very little in the green region. The amount of blue reflected was small for the red samples with the exception of red sample number three which is a bluish-red.

The green samples reflected light to a higher degree in the green region, but in general reflected poorly in the red region. The one notable exception is the sample number five which reflected a high percentage of the red wavelengths.

This might be expected since the sample is a yellow-green. But it is noted that the red region of this sample is still a minimum on the curve.

Secondly, it can be concluded that the highest percentage of reflected light occurs in the region corresponding to the object's color. The most significant conclusion is easily seen with the aid of Table 13 and Figures 13 and 14. These figures show clearly that the minimum reflectance for all objects is in the spectral region of the object's complementary color. It is also significant that the region in which red is a minimum, green is a maximum and where red is a maximum, green is a minimum. Although it is not shown directly by the data, one might also be able to conclude that when a red sensation is seen, one is seeing white light minus the green wavelengths. The converse would also be true that green light is white light minus the red wavelengths.

With respect to the third question it is felt by the investigator that this study does give an interpretation of the reflectance of the colors red and green which should be easily understood by the non-science major.

I. RECOMMENDATION FOR FURTHER STUDY

This study could be further pursued with the use of two monochromators. They could be used to combine any two wavelengths that are supposed to combine to form white light.

The values for these wavelengths could be obtained from chromaticity diagrams.

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